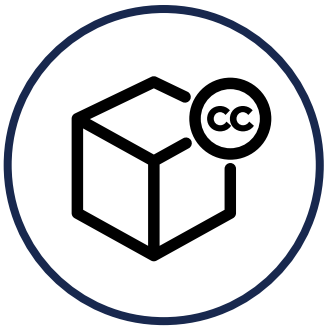
iGEM Boston, MA 2015

UNIVERSITY OF CAMBRIDGE

Open-source Hardware

An iGEM Guide



Cambridge-JIC iGEM Team 2015

Human Practices

Table Of Contents

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With thanks to Dr Jenny Molloy.

The Cambridge-JIC iGEM Team 2015 was a team of 10 undergraduates based at the University of Cambridge, UK. Any views expressed in this article reflect those of the authors, and not the University of Cambridge or any of its departments.

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September 2015
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Foreword

In choosing the novel Hardware Track, this year's Cambridge-JIC iGEM team has come across unexpected challenges. Unsurprisingly perhaps, these have often required us to look into fields of work in which we have little or no experience. This has been particularly true when navigating the world of intellectual property (IP) law, including hardware licensing and design copyright. In developing Open-source Hardware (OSH) as part of the competition, we recognised the need for an accessible, comprehensive and hardware-specific guide to licensing.

This guide is intended as a starting point for future iGEM teams looking to develop hardware for release back into the DIY-bio and 'maker' communities. It can be seen as a companion piece to the guides written by the 2011 Stanford-Brown team explaining IP-law in relation to BioBricks and genetic constructs. Much of the legal infrastructure surrounding OSH is in its infancy, requiring more insight than anticipated. Despite this, we hope that future iGEM teams commit to, and explore the principles of OSH.

It's worth clarifying that although this piece has been well researched, none of the authors are IP-law experts and can only offer advice based on the challenges we've faced (and in some cases even overcome). Ultimately, our most useful contribution to the competition may in fact be ensuring that other teams have an easier time of navigating this often obscure area and can continue where we left-off.

In producing this single document, we hope that future teams will be able to avoid the hours we spent "trawling the web". If you have any improvements to make, don't hesitate to get in touch with the authors via email[1]. Hopefully this summary will start you off, and good luck with your hardware project!

[1] The information presented here is correct to the best of the authors' knowledge. However, the authors would appreciate any feedback, edits or corrections. Get in touch using the email address provided.

Some Definitions

Before moving on to a discussion of Open-Source Hardware Licensing, it's important to establish a few key definitions. The terms below will be used repeatedly throughout the text, but to many people (including the authors) their meaning is often unclear or misunderstood.

License – A permit for an activity that would otherwise be illegal. This can include distributing, using or modifying another's designs or products.

Licensee – A person exercising their rights under the license.

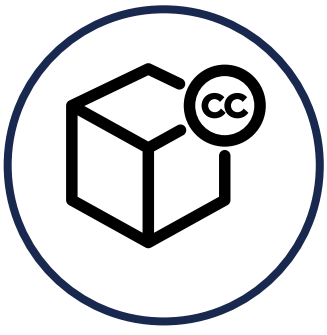
Copyright – A form of Intellectual Property right that gives the creator of a design, artistic work or software exclusive rights to its use and distribution. Different aspects of a creative work can be copyrighted, including its redistribution and modification. These rights can be released or retained by the licensor independently.

Patent – Recognition from the government for an inventor to have exclusive rights to make, use and sell the invention. This is specific to the physical object itself and usually lasts for a limited amount of time. Importantly, the invention must be 'non-obvious'. Note that the legal definition of 'non-obvious' is relatively complicated and will not be discussed here.

As discussed in greater detail below, Copyrights cover creative works only. Within the context of hardware, this can include designs, schematics, source code and circuit diagrams.

Hardware-specific guide

Open-source principles



Licensing options and features

Introduction

The Cambridge-JIC 2015 team has focused on developing hardware that will facilitate the practice of synthetic biology in research and educational settings, namely by creating a low-cost fluorescence microscope. This has the potential not only to make the technique accessible to laboratories with small budgets, but perhaps more significantly to make a previously proprietary piece of equipment customisable and easy to tailor to experimental needs.

"Anyone can study, modify, distribute, make, and sell the design or hardware based on that design"

Importantly, both the hardware and software must be open-source. According to the Open-Source Hardware Association (OSHWA), this means it "is hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design" [1]. This not only requires well-documented procedures but also clear and simple designs that can be modified by non-experts.

The core values of the movement reflect the power of collaboration in troubleshooting and improving designs. In contrast, closed hardware relies heavily on complicated designs and patent law to prevent attempts at recreation and modification [2]. Scientific experiments have widely different requirements in terms of software and hardware, requiring flexibility at odds with the difficulty of remixing commercial lab hardware. Only very recently however has the scientific community begun to address the need for low-volume production of equipment that can be tailored to specific protocols [3].

OSH is "free as in free speech, not free beer"

It is worth mentioning that while this article is written in the context of scientific hardware, the OSH revolution extends much further than this, and is fully compatible with a commercial business plan. Universally, it has the potential for "market expansion, innovation, acceleration, educational enhancement and medical care improvement" [3]. That said, one must remember that OSH is "free as in free speech, not free beer" or more formally *Libre* rather than *Gratis* [4]. For example, the Arduino microcontroller[2] designs are freely available online but the foundation also sells them for a profit for funding. Arduino is registered as a trademark too, which protects the brand from cheap replicas [5].

[2] According to arduino.cc "Arduino is an open-source prototyping platform based on easy-to-use hardware and software". In our project, we use Arduinos to control servomotors and LEDs within the microscope.

Licensing

Outline

One of the fundamental issues encountered by all developers of OSH is the surprising fact that it's actually extremely difficult to put something into the public domain under a fully comprehensive legal framework. It requires licenses that ensure the maximum number of people possible have access to the designs, software and the finished product itself (Fig. 1).

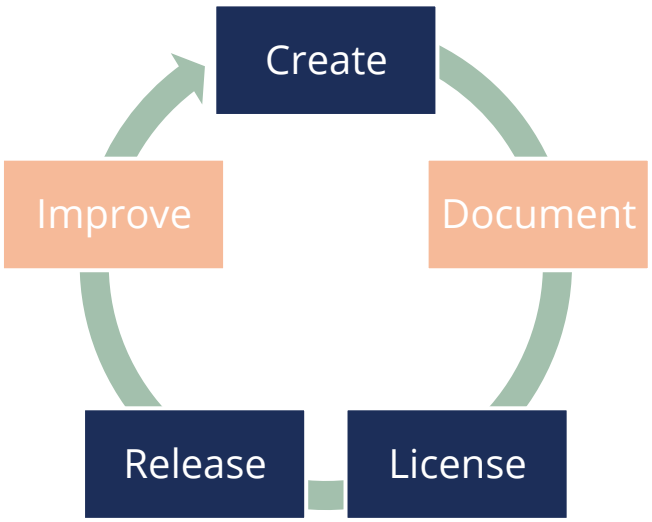


Fig. 1: *An overview of the OSH evolution cycle. In a viral license system, the license is the same in each cycle.*

An important distinction must be made when considering copyrights and patents. In general, licenses grant the legal right to use copyrighted information. However, under the legal definition copyrights cannot be placed on useful or functional objects [6][7]. They extend solely to creative works. This is where the difficulty for hardware lies: copyright doesn't apply in the same way. Instead patents are usually used to protect IP rights.

Unlike copyright, which applies automatically under most legal frameworks, patents must be applied for. As discussed extensively by the Stanford-Brown iGEM team, patents are both difficult to obtain and interpret. They can also be extremely expensive to initiate and maintain (one estimate is upwards of $4,000 for a simple patent) [7]. Under US law, the Distinction between creative works (copyright) and useful works (patent) is described by 17 U.S.C. § 102 [8]. The UK copyright service suggests that patents typically take 2-3 years to be granted [9].

In the case of OSH, copyright law can be more useful when considering the software and designs (e.g. CAD schematics) while patent law is more applicable to the finished product. The difficulty is that both must be used creatively to develop an open-source license. Overall, the focus with OSH is on the patent aspect: this controls the use and manufacture of the device built from the designs, rather than the distribution of the documentation itself [1][2]. Many forms of license are not compatible with current patent law, and are often based on more established OSS licenses. To summarise: licenses that cover documentation, software and computer code are copyright licenses. Those that also include hardware manufacturing and distribution are not primarily copyright licenses.

By licensing hardware, the creators can express their intent for its use, including:

i. Ensuring correct attribution
ii. Controlling whether it can be derivatised
iii. Determining whether derivatives can be made proprietary

The rest of the article focuses on using licenses to clarify these intentions.

Copyleft options available

The phenomenon of OSH is in its infancy, and as a result there are only a handful of potential options when choosing an appropriate license. Many of these are Copyleft or 'viral' licenses, meaning derivatives must be released under the same license. One of the most widespread is the Creative Commons[3] Attribution-ShareAlike license (Fig. 3, Fig. 4). As with all creative commons licenses, this is not applicable to hardware, and was instead developed for works of art such as music and designs, as well as documentation [2]. More comprehensive and hardware-specific licenses have been created, and here the authors will focus on two of them: the CERN OHL and the TAPR OHL.

Fig. 2: *The Copyleft logo. The term was coined by Richard Stallman.*

The CERN OHL was developed to do for hardware what the General Public License (GPL) did for software, and is available for free download[4]. In 2009, scientists in the community at CERN began to create the Open Hardware Repository: "a place on the web for electronics designers at experimental physics facilities to collaborate on open hardware designs, much in the philosophy of the free software movement" [10].

The fundamental principal of the CERN OHL is that if modifications are to be released to the community, they must be under the same license scheme as the original product. This

[3] A global non-profit organization that enables sharing and reuse of creativity and knowledge through the provision of free legal tools (wiki.creativecommons.org).
[4] See http://www.ohwr.org/documents/294 for more information.

ensures that the license is persistent, and ultimately everyone in the community benefits. In essence, the license ensures that the process of improvement uses collaboration between anyone in the community.

CERN itself uses the license to release Printed Circuit Boards (PCBs) that it develops back into the physics community (Fig. 5). In fact it was originally developed for their White Rabbit project, which was implemented to synchronise nodes with high accuracy over long distances. The hope was that the hardware released would be used outside the small community of high-energy physics, and impact on lives far beyond the scope of CERN's direct research. CERN also recognised the potentially huge benefit of releasing hardware to the community, where it is effectively peer-reviewed and reconfigured to precisely match end-user requirements [10].

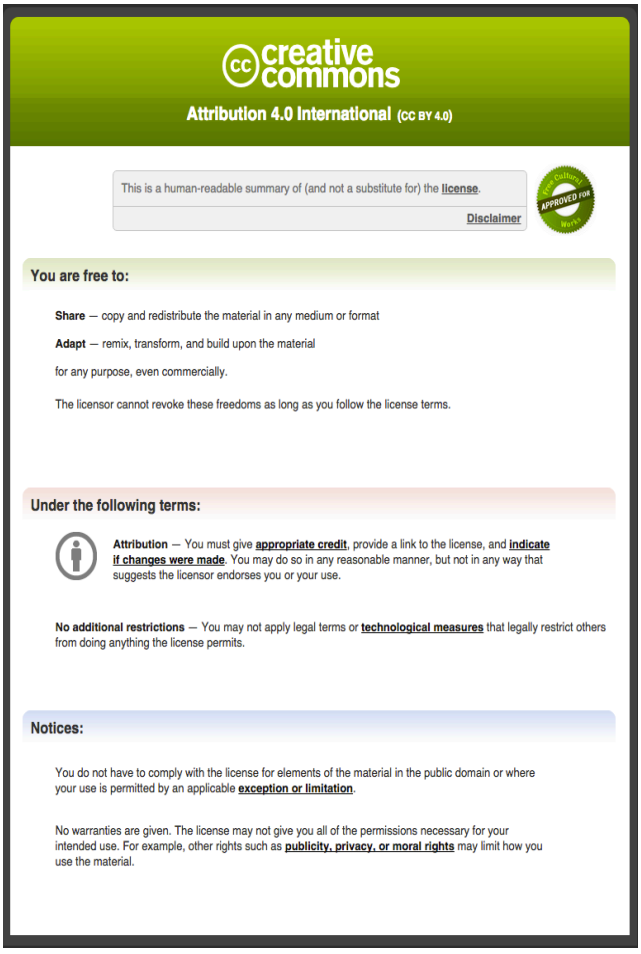


Fig. 3: *An example of the human-readable version of the most recent Creative Commons Attribution-ShareAlike license (CC BY-SA).*

The key features of the CERN OHL are outlined below, as described by the official documentation [10]:

i. The license covers the distribution of documentation, and the distribution and manufacture of products

ii. The licenses does not extend to code, software or firmware loaded on to electronic devices[5] unless specifically expressed

iii. The license does not represent the transfer of IP rights to the Licensee

iv. Any modification to the documentation by the Licensee must be clearly noted

v. The Licensee must distribute all modified documentation under the same, or future versions of the same, OHL

The information above relates to the most recent version of the license (v1.2).

[5] These can be licensed under software specific licenses, or perhaps the slightly stranger 'Do What the Fuck You Want To Public License'. For more information about this, visit http://www.wtfpl.net/

Notable new projects that have taken up the CERN OHL include Adafruit Industries and Citoyens Capteurs, which aims to develop a network of citizen air pollution sensors (amongst other OSH programs) [11]. An interesting result of the idea of OSH is that many small, educational STEM projects that adopt the CERN license offer the option to buy complete packages of all the components necessary to create the product, as well as letting people build from scratch. This demonstrates that the concepts of OSH are not incompatible with commercial enterprises.

The TAPR OHL (Fig. 6) was developed by Tucson Amateur Packet Radio, and like the CERN OHL was created to extend the success of OSS licenses[6]. It is available for anyone to use, and can be downloaded directly from their website[7] [12]. Just like the CERN OHL it is a Copyleft or 'viral' license: the terms applied to one product are propagated to all downstream products. In short, this means that once a product is made open-source, it and all it's modifications remain accessible to the community. Again, like the CERN OHL it is also a hardware-specific license, meaning that it is not predominantly a copyright license.

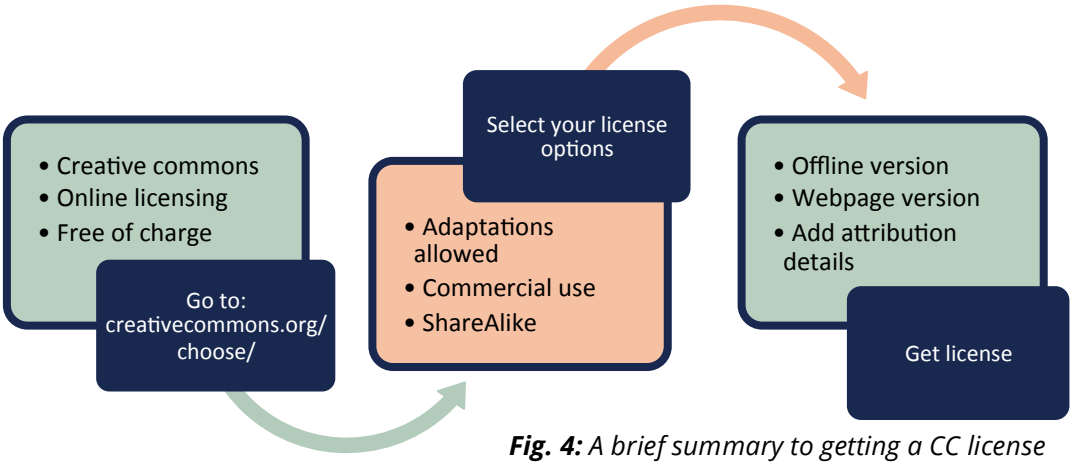


Fig. 4: *A brief summary to getting a CC license for your designs, software and literature.*

The key premises of the TAPR OHL are outlined below, as described by the official website [12]:

i. Products can be used for any legal purpose
ii. Unmodified documentation can be released, but it must be in the form of the entire package
iii. Products can be commercially released as long as the documentation is also freely released, or is available for free for up to 3 years
iv. All modifications must be released under the OHL
v. All modifications must be well documented, and attempts made to notify the designers of the original product (see Supplementary Information for details)

[6] It is worth mentioning that these licenses were created by volunteers with expertise in legal matters. They did this for the benefit of the community itself, despite it being a complex and time-consuming process.
[7] See https://www.tapr.org/ohl.html for more details.

Choosing between the CERN and TAPR OHLs

Overall, the above requirements ensure that nobody is denied the rights to access the product and its documentation, including all downstream versions. In this sense the two hardware licenses are similar. The most significant difference between the TAPR OHL and the CERN OHL is that the TAPR OHL attempts to deal directly with the patent aspect of hardware licensing, and currently is the only license to do so [13]. As mentioned previously, the aspects of hardware such as manufacture and use mean that it is not covered by copyright, and instead must be regulated under patent law[8].

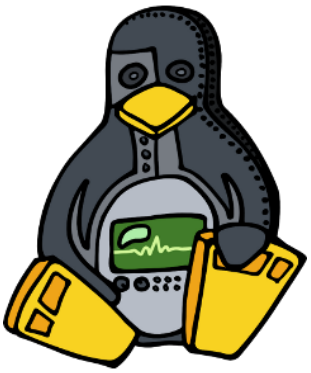


Fig. 5: *The logo of the Open Hardware Repository founded by CERN.* ***Source****: www.ohwr.org*

This makes the license extremely powerful if the original creator of the hardware patented their creation: they can waive their right to IP rights and provide full access to all downstream licenses. However, a problem arises when the Licensor does not have patent rights over the creation [13]. The cost and complexity of obtaining a license a significant obstacle that the creator must attempt to overcome if they want to patent their creation. If anyone else asserts IP rights over the creation under license, then access to the creation is no longer universal under the TAPR OHL.

Fig. 6: *The symbol of the TAPR OHL.* ***Source****: www.tapr.org*

Ultimately the choice is yours: the TAPR OHL is particularly effective if the patent rights for the original work belong to the licensor, but it also has its drawbacks. As a license TAPR is older, but the CERN OHL has the backing of a strong community of physicists and does not deal as directly with patent rights.

"The TAPR OHL attempts to deal directly with the patent aspect"

[8] A reminder: copyright covers creative works such as designs, diagrams, software and other documentation. Patents are applicable to inventions and useful works as physical entities (the finished product).

Permissive licenses – an alternative to Copyleft

Fig. 7: *The BSD and MIT license*

Copyleft licenses were developed in the context of Open-source Software[9] (OSS), and although the CERN and TAPR OHLs attempt to translate their principles into the OSH community this can be problematic [14][15]. Copyleft licenses are legally complex, and restrict licensing of derivative products to the same licenses [16] [17]. To some this represents an infringement on freedoms rather than an enforcement of them. Permissive licenses are designed to be simple and compatible with a greater variety of downstream licenses (see Supplementary Information for compatibility chart). In contrast to Copyleft licenses, they make it more likely that a given product will be repackaged and commercialised [16]. It is important to note that unlike the CERN and TAPR OHLs, Permissive licenses are copyright licenses and therefore applicable the to software, documentation and designs of hardware projects.

The difference between the two license types arises from the fact that there are no reciprocity requirements when using a Permissive license. Redistributors can restrict access to derivative products and make them proprietary [18], and the option for commercialisation is seen as a driving force for innovation [14]. One consideration that should be made is the ability of downstream licensers to use newly developed licenses on their derivative products that are compatible with the original license. Due to the specificity and complexity of Copyleft licenses this might not be possible unless a Permissive license is used. A variety of Permissive licenses are available (Fig. 7, Fig. 8), and it has been proposed to develop a new one based on the Apache 2.0 software license as this is already well established [14]. It is important to recognise that any improvements on the product that are made proprietary will not be available to the community.

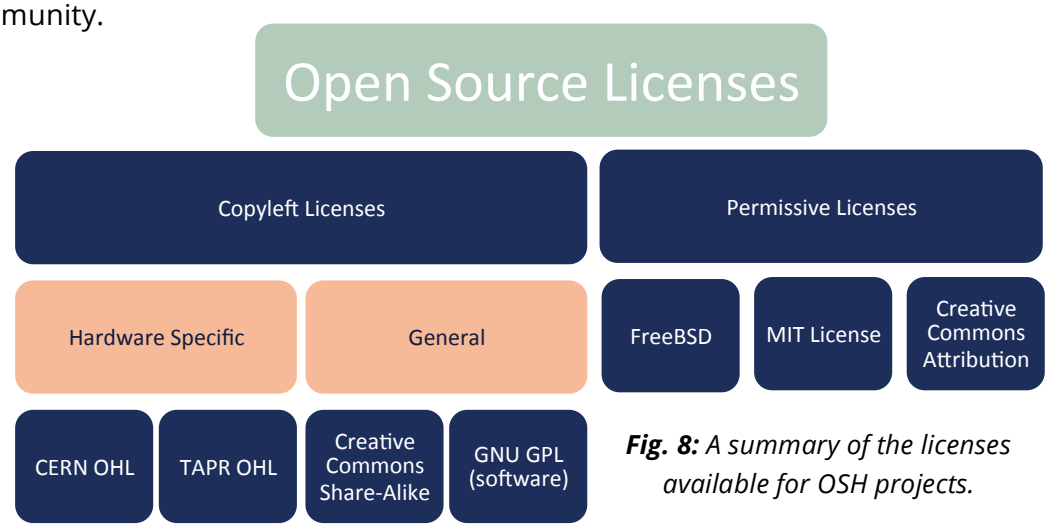


Fig. 8: *A summary of the licenses available for OSH projects.*

[9] The phenomenon of OSS predates that of OSH by over a decade, and is therefore better established. This includes a more comprehensive legal framework for licensing.

Best practices

OSHWA has put together an extensive outline of the procedures and requirements for implementing an OHL. This is available on their website, but below is an abridged version [1]:

i. Ensure a copy of your license is clearly present on your product. This may include a web link to the license
ii. Clearly specify the components that are open-source
iii. Put the OSHW logo (Fig. 9) on your hardware and use these guidelines (available online)
iv. Keep your source files in a (free) publicly available source code repository like Github. Version control means any modifications can be tracked easily

"The tools for [version control] are still pretty weak for hardware projects, but for software, they're mature."

OSHWA highlights the fact that the tools for recording modifications to the designs "are still pretty weak for hardware projects[10], but for software, they're mature" [1]. As the authors have found, comprehensive documentation of the hardware project although essential can be extremely time-consuming. Future iGEM teams must always bear in mind that the hardware they develop must be presented in such a way as to allow others to reproduce and modify it with ease[11].

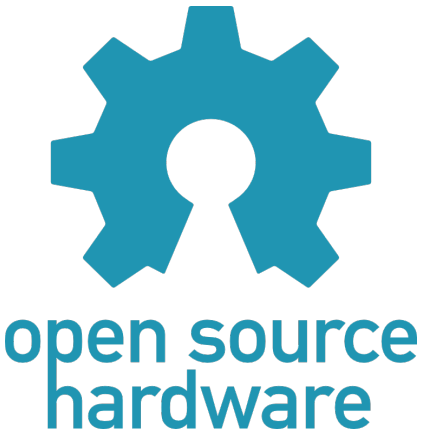


Fig. 9: *The official OSHW logo from the OSHWA website. This should be displayed on all hardware under the license.*

[10] Reasons for this could be that hardware design files are often a) not standardised and b) in a binary format, specific to the program that wrote it.
[11] At the time of writing, the Cambridge-JIC team are preparing to document the project using under-development software that standardises the process. This will hopefully be released in time for more details to be published on our wiki.

Quick guide

The section on hardware licensing is summarised below (Fig. 10). This is intended for quick reference, and more details are found in the text and in the Supplementary Information.

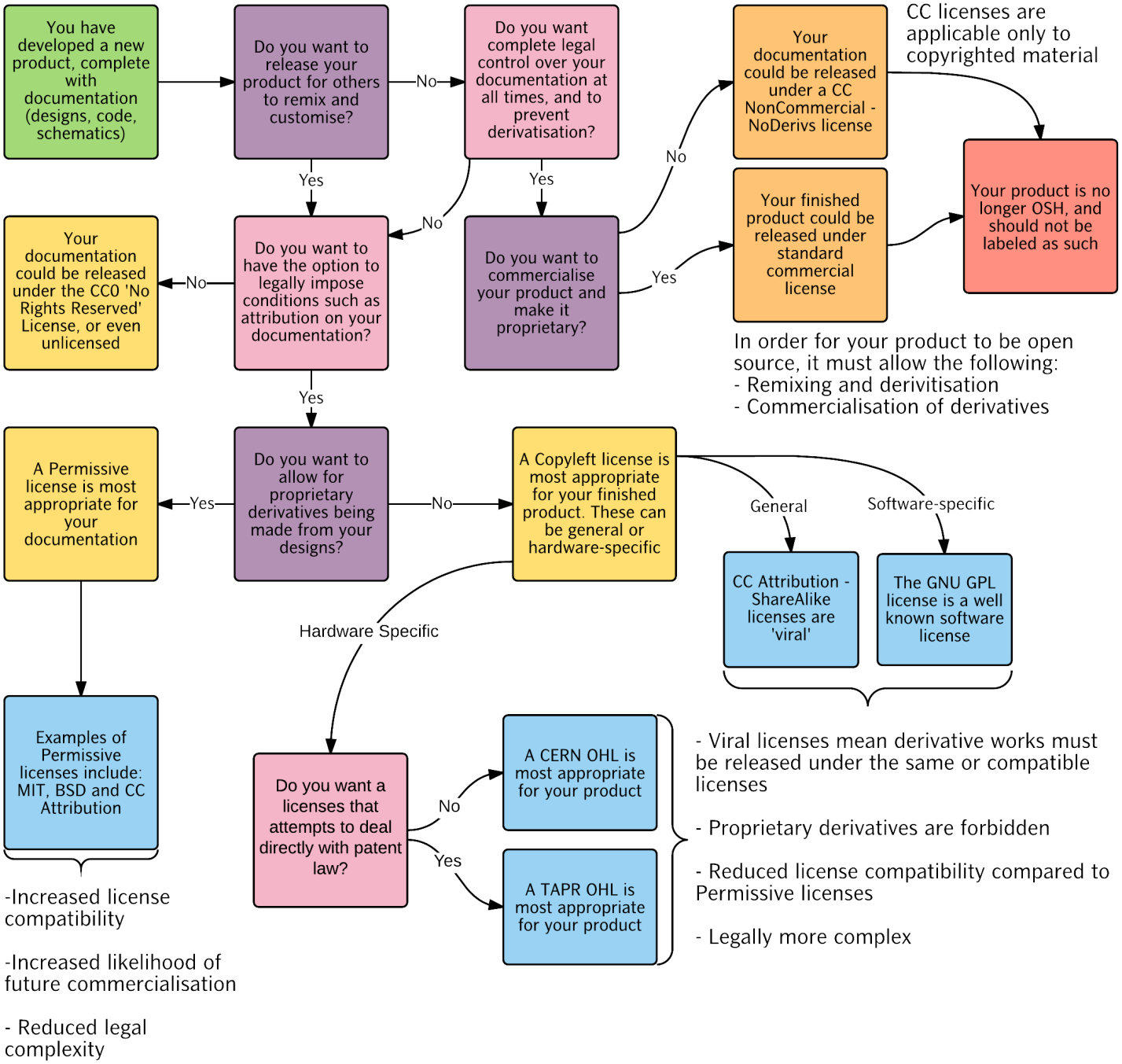


Fig. 10: *A quick guide to choosing a license. Note that this list is not exhaustive, and should not be taken as legal advice. For more detailed information, read the Licensing section of the article and see the Supplementary Information.*

Supplementary Information

Documentation requirements

If you create a design that you want to license under the TAPR OHL, you should [12]:

i. Include the OHL document in a file named LICENSE.TXT (or LICENSE.PDF) that is included in the documentation package.
ii. If the file format allows, include a notice like "Licensed under the TAPR Open Hardware License (www.tapr.org/OHL)" in each documentation file. While not required, you should also include this notice on printed circuit board artwork and the product itself; if space is limited the notice can be shortened or abbreviated.
iii. Include a copyright notice in each file and on printed circuit board artwork.
iv. If you wish to be notified of modifications that others may make, include your email address in a file named "CONTRIB.TXT" or something similar.
v. Any time the OHL requires you to make documentation available to others, you must include all the materials you received from the upstream licensors. In addition, if you have modified the documentation:
vi. You must identify the modifications in a text file (preferably named "CHANGES.TXT") that you include with the documentation. That file must also include a statement like "These modifications are licensed under the TAPR Open Hardware License."
vii. You must include any new files you created, including any manufacturing files (such as Gerber files) you create in the course of making products.
viii. You must include both "before" and "after" versions of all files you modified12.
ix. You may include files in proprietary formats, but you must also include open format versions (such as Gerber, ASCII, Postscript, or PDF) if your tools can create them.

If you create a design that you want to license under the CERN OHL:

x. Modified Documentation must carry prominent notices stating that the Licensee has modified the Documentation, with the date and description of the modifications
xi. Documentation must carry a new Documentation Location notice if the original Documentation provided for one
xii. Modified Documentation must be available at the same level of abstraction as that of the Documentation, in the preferred format for making modifications to it (e.g. the native format of the CAD tool as applicable), and in the event that format is proprietary, in a format viewable with a tool licensed under an OSI-approved license if the proprietary tool can create it
xiii. The modified Documentation must be released under the terms and conditions of this Licence or, where applicable, a later version of this Licence as may be issued by CERN

[12] This is seen as a significant impracticality inherent in the TAPR OHL. Here it could be easier to link to the original version. Github allows you to do this by “forking” existing repositories to a new one. If you want to contribute back, you can send your changes back by sending a so-called "pull request" back to the original repository as a request to pull your new code into the original repo.

Useful software for developing OSH

Below is a list of software programs that the authors have found useful for developing OSH, supplemented with other commonly used programs [13]:

i. OpenSCAD – a free, open-source, parametric CAD platform used to design 3D objects for printing (available from http://www.openscad.org)
ii. Tracker – a free, open-source, video analysis and modelling tool. Used to track moving objects in videos and extract data (available from http://physlets.org/tracker/)
iii. Cura 3D – a free, open-source 3D printer interface from Ultimaker. Used to control printer settings (available from https://ultimaker.com/en/products/cura-software)
iv. Fiji - a free, open-source image processing and analysis platform. Particularly useful for microscopy (available from http://fiji.sc/Fiji)
v. Inkscape – a free, open-source vector graphics package. Extremely useful for 2D design followed by linear extrusion (available from https://inkscape.org/en/)
vi. DesignSpark – a free electronics design software for PCB prototyping. Has an online library of over 80,000 parts (available from http://www.rs-online.com/desig-nspark/electronics/)
vii. Scribus – a free, open-source graphics software. Particularly useful for publishing (available from http://www.scribus.net/)
viii. OpenCV – A FOSS released under a BSD license that provides a library for image processing software (available from http://opencv.org/)

[13] For a detailed list of free, open-source software programs available visit http://www.datamatio-n.com/open-source/open-source-software-list-2015-ultimate-list-1.html

Compatibility charts for different licenses

The table below (Fig. 11) indicates the compatibilities of the Creative Commons licenses with one-another, as described on their website.

	Public Domain Mark	CC0	CC BY	CC BY-SA	CC BY-NC	CC BY-ND	CC BY-NC-SA	BY-NC-ND
Public Domain Mark	✓	✓	✓	✓	✓	✗	✓	✗
CC0	✓	✓	✓	✓	✓	✗	✓	✗
CC BY	✓	✓	✓	✓	✓	✗	✓	✗
CC BY-SA	✓	✓	✓	✓	✗	✗	✗	✗
CC BY-NC	✓	✓	✓	✗	✓	✗	✓	✗
CC BY-ND	✗	✗	✗	✗	✗	✗	✗	✗
CC BY-NC-SA	✓	✓	✓	✗	✓	✗	✓	✗
BY-NC-ND	✗	✗	✗	✗	✗	✗	✗	✗

Fig. 11: *A compatibility table comparing the Creative Commons licenses. Note that some of the CC licenses above are not compatible with open-source hardware. BY = Attribution, ND = NoDerivs, NC = NonCommercial, SA = ShareAlike.* ***Source:*** *Adapted from creativecommons.org* [19].

The diagram below (Fig. 12) indicates the relationships between common OSH licenses, and their categorisation as Permissive/Copyleft. The arrows indicate compatibility in a directional sense. The names in the boxes represent common licenses, and the '+' means 'and all later versions'. David Wheeler created this graph in the context of OSS, but some of the licenses are applicable to hardware documentation, specifically the MIT and BSD-new licenses. For a clarification of some of the terms, see the glossary (pg. 17).

The CERN OHL and TAPR OHL both stipulate that all documentation (including software) can be licensed under same license. However, alternatively strongly protective Copyleft licenses (see below) are compatible with both of the hardware-specific licenses when considering the code, firmware or software associated with electronic devices in the final product [10] [12].

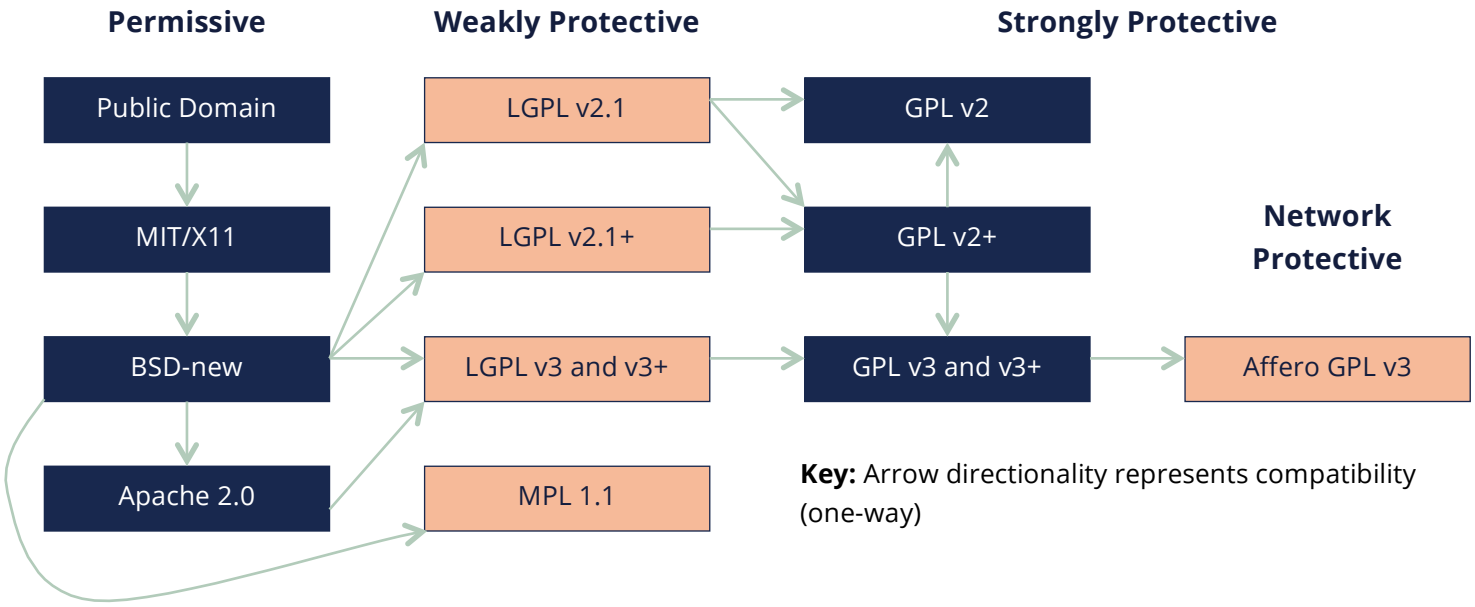


Fig. 12: *A compatibility diagram indicating the relationship between common open-source licenses.* ***Source****: Adapted from dwheeler.com/essays/floss-license-slide.html under the Attribution-Share Alike 3.0 License* [17].

Glossary of Terms

Arduino - An open-source prototyping platform based on easy-to-use hardware and software. It is a microcontroller that is programmed through the Arduino software IDE (arduino.cc).

CAD – Computer Aided Design. The use of computer programs to make high precision 2D and 3D designs.

CERN OHL – An open hardware license developed and used by CERN (European Organisation for Nuclear Research) based on Copyleft principles.

Compatibility – An issue that arises when different licenses have conflicting requirements that prevent them form being combined. A particularly common issue with software.

Copyleft – A license type that allows products, designs and software to be released freely for modification, distribution and use. Any derivatives must be licensed under the same conditions.

Copyright – A legal right that gives the creator of a design, artistic work or software exclusive rights to its use and distribution. In most cases they last for a limited amount of time.

Creative Commons - A global non-profit organization that enables sharing and reuse of creativity and knowledge through the provision of free legal tools (wiki.creativecommons.org).

Git – a revision control system created by Linus Torvalds for the Linux kernel. It allows modifications to be tracked and recorded.

Github – An online Git repository that has a number of additional features to version control such as a graphical interface (https://github.com/).

GPL – General Public License. The most widely used free software license, and the first Copyleft license released for general use.

License – A permit for an activity that would otherwise be illegal. This can include distributing, using or modifying another's designs or products.

Licensee – A person exercising their rights under the license

Network Protective – A form of Copyleft license that has provisions for the use of software over a computer network. Code must be made available for people accessing the network.

Open-source - Hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design (oshwa.org).

OSHWA – Open-source Hardware Association. An organisation that provides information and best practices for releasing open-source hardware.

Patent – Recognition from the government for an inventor to have exclusive rights to make, use and sell the invention. Usually lasts for a limited amount of time.

PCB – Printed Circuit Board. A board that connects electronics components using conductive tracks on an insulating board.

Permissive License – An open-source hardware license that permits derivatives of the product to be made proprietary.

Proprietary – A product privately owned by an individual or corporation under patent or trademark, and therefore not open to be modified, remixed or redistributed.

Strongly Protective – A form of Copyleft license that adheres to all the standards of the Copyleft principles.

TAPR OHL – An open hardware license developed and used by Tucson Amateur Packet Radio under the principles of Copyleft.

Viral – A casual term for Copyleft licenses, referring to Copyleft licensed code 'infecting' proprietary software.

Weakly Protective – A form of Copyleft license that has elements of a Permissive license. Computer code cannot be made proprietary, but can be made part of a larger proprietary program.

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